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# Large-scale star formation in the Magellanic Clouds

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## Abstract

In this contribution I will present the current status of our project<sup>1</sup> of stellar population analyses and spatial information of both Magellanic Clouds (MCs).

The Magellanic Clouds are suitable laboratories and testing ground for theoretical models of star formation. With distance moduli of 18.5 and 18.9 mag for the LMC and SMC, respectively, and small galactic extinction, their stellar content can be studied in detail from the most massive stars of the youngest populations ( $< 25$  Myr) connected to  $H\alpha$  emission down to the low mass end of about  $\frac{1}{10}$  of a solar mass. Especially the LMC with its large size and small depth ( $< 300$  pc) is a preferred target to constrain star formation mechanisms.

Based on broad-band photometry ( $U, B, V$ ) I present results for the supergiant shell (SGS) SMC 1, some regions at the LMC east side incl. LMC 2 showing different overlapping young populations and the region around N 171 with its large and varying colour excess, and LMC 4. This best studied SGS shows a coeval population aged about 12 Myr with little age spread and no correlation to distance from LMC 4's centre. I will show that the available data are not compatible with many of the proposed scenarios like SSPSF or a central trigger (like a cluster or GRB), while a large-scale trigger like the bow-shock of the rotating LMC can do the job.

## 1 Introduction

On deep pictures of the Magellanic Clouds (MCs) taken in  $H\alpha$  light, Meaburn and collaborators (cf. Meaburn 1980) recognized ten huge 'bubbles' with diameters of 600–1400 pc, the so-called supergiant shells (SGSs or supershells). These huge shells, according to Goudis & Meaburn (1978), build a new group different from the smaller ( $< 260$  pc) giant shells (GSs or superbubbles).

These structures need very effective creation mechanisms and collisions of high velocity clouds (HVCs) with the disk of the galaxy or stochastic self-propagating star formation (SSPSF) have been proposed. Both might explain the ring of H II regions and the 'hole' in the H I layer, as observed in the case of LMC 4. According to the SSPSF model, star formation would 'eat' its way from the initial point to all directions through the interstellar medium, creating a big cavity and a thick outer shell of neutral hydrogen ionized at the inner edge by the early-type stars (O-B2). Thus one should see a clear age gradient from the centre to the rim.

This contribution will give first results for the SGS SMC 1, summarize the study at the east side of the LMC with a focus on LMC 2 and N 171, and ends with a short update (cf. Braun 1998; Braun et al. 1997) of knowledge about the stellar content of LMC 4 and its implications on the creation mechanism.

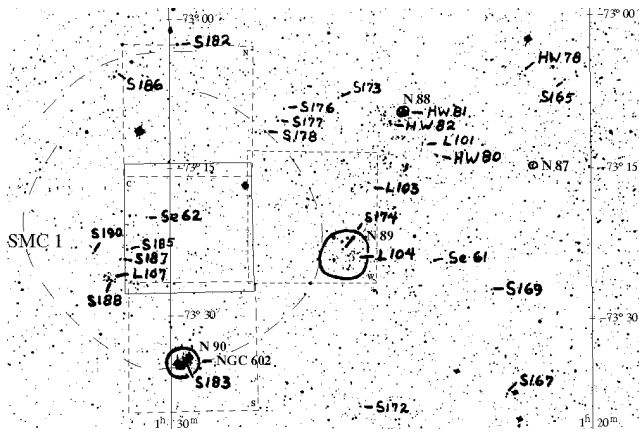
<sup>1</sup>The project is a collaborative effort with Klaas S. de Boer, Martin Altmann, and Holger Schmidt from the Sternwarte Bonn, Antonella Vallenari from the Astronomical Observatory in Padova, Ulrich Mebold from the Radioastronomical Institute in Bonn, and Jean-Marie Will, formerly at the Sternwarte Bonn, in the framework of the Bonn/Bochum - Graduiertenkolleg.

## 2 First results of a study inside SMC 1

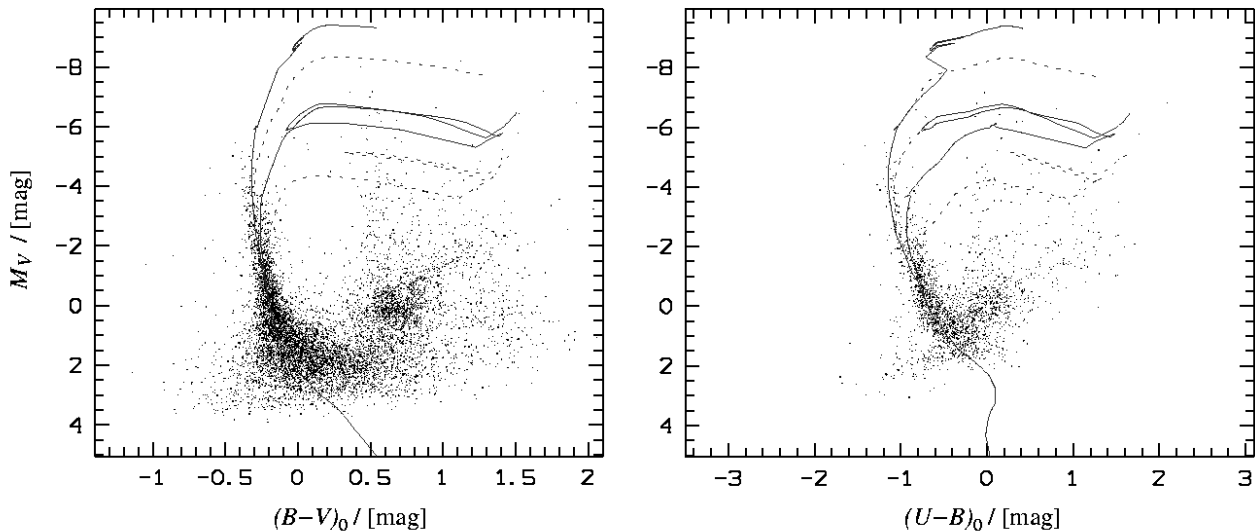
SMC 1 ( $\equiv$  DEMS 167) is the only supergiant shell (SGS) detected by Meaburn and collaborators (see e.g. Meaburn 1980, Fig. 3) in the Small Magellanic Cloud. It has a diameter of about 600 pc, as indicated by the rough dashed boundaries in Fig. 1. Its  $H\alpha$  appearance is not as regular as that of LMC 4, with pronounced emission from south (incl. N 90  $\equiv$  DEMS 166) to east, in the northwest, and with a double ‘rim’ in the north. From the east rim the emission extends toward NE via N 89 ( $\equiv$  DEMS 164) to N 88 ( $\equiv$  DEMS 161).

The presented photometry has been taken at the 1.54 m Danish Telescope at ESO observatory on Cerro La Silla with DFOSC and the  $2k^2 \text{ pix}^2$  LORAL CCD (W7 Chip;  $12.9' \times 12.9'$  field of view) by me in January 1998 (C,S), and by Martin Altmann in November 1999 (N,W; only  $B, V$ ).

The CMDs with fitted isochrones in Fig. 2 reveal a small young population of  $\sim 8$  Myr and a second population of at least 20 Myr (see Braun 2001; Braun et al. 2001b for more details).



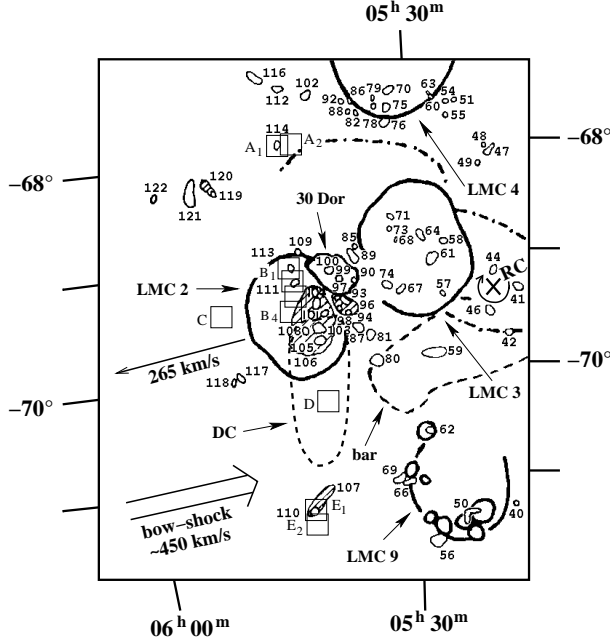
**Fig. 1.** Mosaic of the central SMC wing region (Shapley 1940) out of  $V$  charts of the Hodge & Wright (1977) atlas. The four fields (north, centre, south, west) of the presented dataset in this supergiant shell are outlined, with the  $H\alpha$  rim of SMC 1 roughly indicated by the dashes.



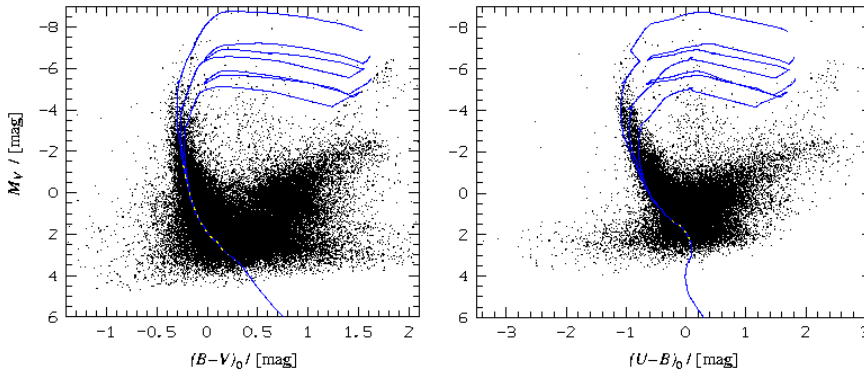
**Fig. 2.** CMDs of the entire SMC 1 region (see Fig. 1) with the isochrones of the Geneva group (Charbonnel et al. 1993) for SMC metallicity ( $Z = 0.004$ ) of logarithmic ages  $\log(t/[\text{yr}]) \in \{6.8, 7.0, 7.3, 7.7\}$  and applied colour excess of  $E_{B-V} = 0.12 - 0.19$  mag. The  $B - V$  diagram contains 8 704 data points, the  $U - B$  a total of 2 166.

### 3 Stellar populations at the LMC east side

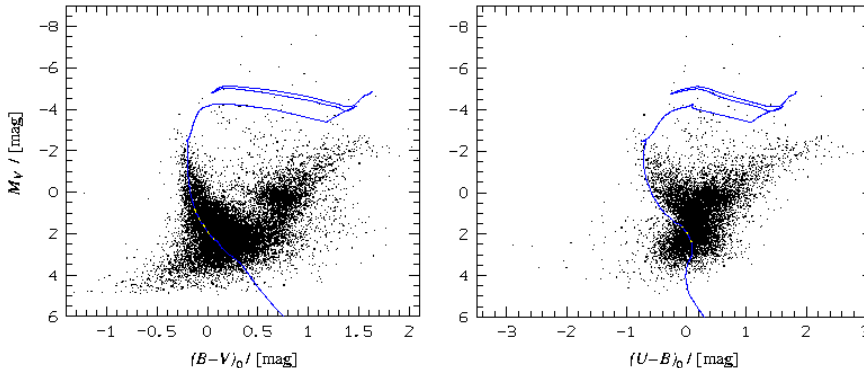
In 1996 I observed five regions located at the LMC east side with 10 CCD positions in  $U, B, V$  passbands with the 1.54m Danish Telescope. These regions (see Fig. 3) are from north to south: the giant shell N 70 (region  $A_{1-2}$ , cf. Braun 1998), a strip inside SGS LMC 2 ( $B_{1-4}$ ), an outer field east of LMC 2 (C), the region around N 171 (D), and the southern part of N 214 ( $E_{1-2}$ ). Here I will concentrate on LMC 2 and N 171 data (see Braun 2001; Braun et al. 2001a for further information).



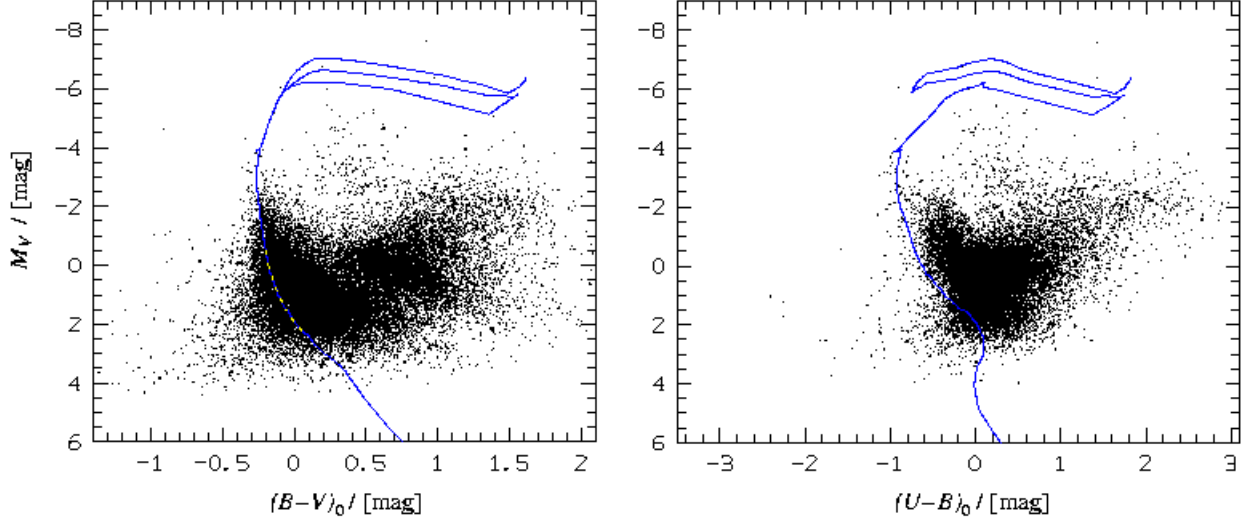
**Fig. 3.** Sketch of the large-scale features (see Mizuno et al. 2001 for a detailed map of the dark cloud, DC) and OB associations at the LMC east side. Additionally, the 5 regions (A-E) out of 10 CCD positions are indicated. The position of the rotation centre, RC, and the movement of the LMC in the galactic halo are indicated by the direction of rotation and proper motion. The resulting bow-shock, driven by the sum of motion and rotation, is  $\sim 450 \text{ km s}^{-1}$  (see de Boer et al. 1998; de Boer 1998).



**Fig. 4.** CMDs of the entire strip inside LMC 2 ( $B_{1-4}$ ) with Geneva isochrones (see Schaerer et al. 1993;  $Z = 0.008$ ) of logarithmic ages  $\log(t/\text{yr}) \in \{6.9, 7.2, 7.5\}$  and applied  $V$  extinction of 0.68 mag.



**Fig. 5.** CMDs of the outer field east of LMC 2 (C) with Geneva isochrones (Schaerer et al. 1993;  $Z = 0.008$ ) of logarithmic ages  $\log(t/\text{yr}) = 7.7$  and applied  $V$  extinction of 0.65 mag.



**Fig. 6.** CMDs of the region around N 171 (D) with Geneva isochrones (Schaerer et al. 1993;  $Z = 0.008$ ) of logarithmic ages  $\log(t/[\text{yr}]) = 7.25$  and applied  $V$  extinction of 0.96 mag. One should note that the isochrone has only been fitted to the youngest and less reddened stars of the  $B - V$  diagram.

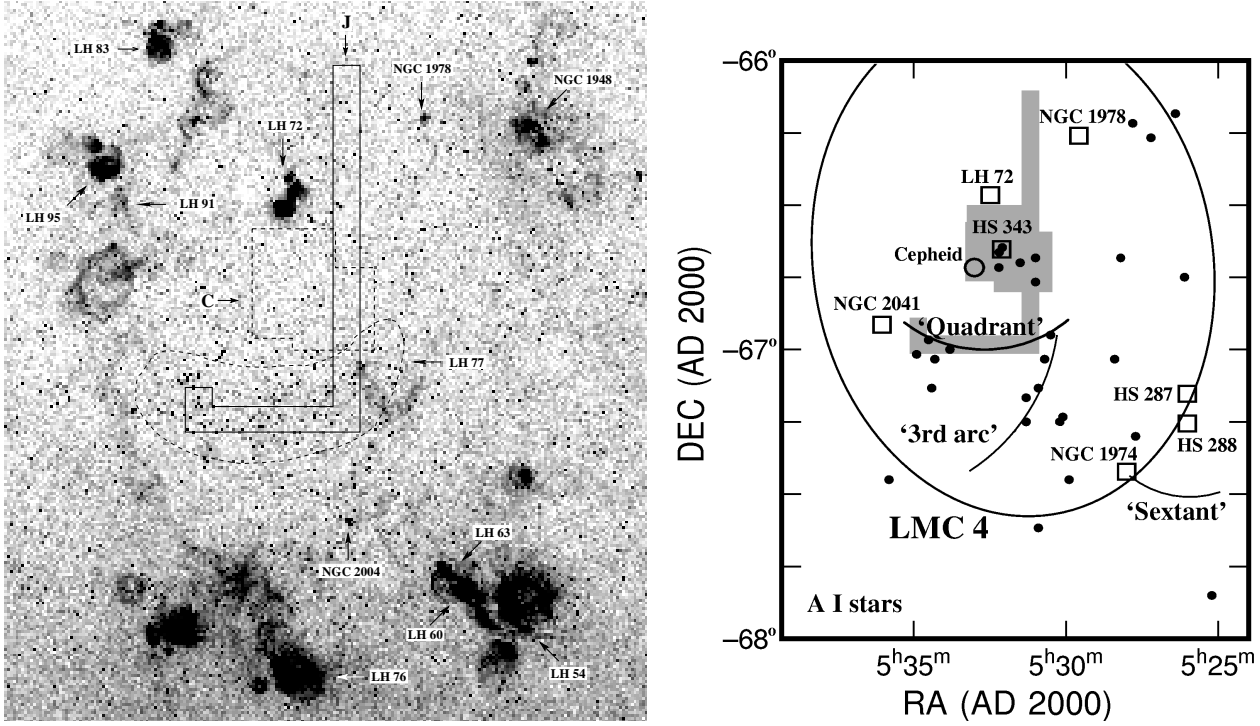
Figs. 4 and 5 show the CMDs of the entire strip inside LMC 2 and of the outer field, respectively. While the CMDs of the outer field only show a stellar population of about 50 Myr and older, the CMDs of the strip containing N 164, NGC 2100, and NGC 2102 reveal a mixture of young populations (present in all four fields), covering the interval from 8 to 32 Myr. While the two southern fields are similar, the two northern show differences in the age structure by a component younger than 8 Myr concentrated on N 164 ( $B_1$ ) and a 16 Myr component of NGC 2100.

For N 171, the youngest population discovered in the CMDs (Fig. 6) has an age of about 18 Myr. This region was selected at the locus of an X-ray shadowing region (cf. Blondiau et al. 1997) and shows extraordinary reddening with a large spread. The colour extinctions ( $E_{B-V}/[\text{mag}]$ ) derived from the reddening free parameter  $Q$  (peak of the distribution with FWHM in '()') and from the isochrone fit (in '[ ]') are: 0.075 (0.08) [0.11] for N 70 ( $A_1$ ), 0.14 (0.08) [0.21] for the outer field east of LMC 2, 0.17 (0.11) [0.19] for N 214, 0.185 (0.16) [0.22] for the LMC 2 strip, and **0.29 (0.24) [0.31]** for the **N 171** region. One should note that the peak of the distribution is shifted from the mean and that the isochrone fit is based on the youngest and for N 214 not numerous population, which may have a different reddening than most other stars (maybe due to unrevealed 3d structure).

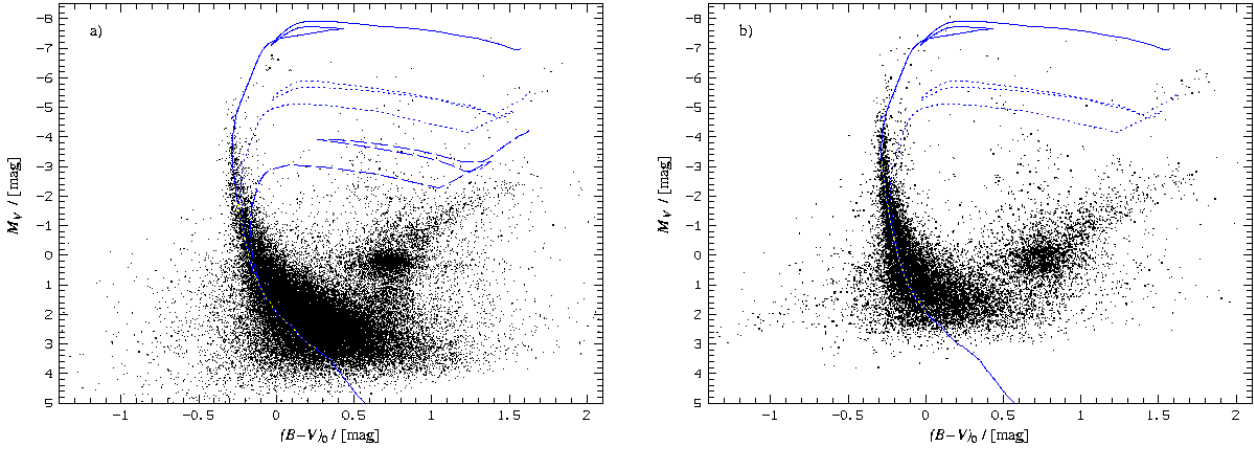
## 4 Supergiant shell LMC 4 and its large-scale triggered origin

Our first  $B, V$  photometry inside LMC 4 (a 'J'-shaped region, see Fig. 7) taken in 1993 with the 0.91 m Dutch Telescope (Braun et al. 1997; Braun 1998) has shown, as given in Fig. 8b, that the central superassociation, LH 77, has an age of 11 – 13 Myr. This population is present in the entire interior of this supergiant shell and at the inner rim region (e.g. LH 63). The associations at the rim tend to show age gradients with younger ages for associations more distant from the inner rim of  $H\alpha$  filaments (see Gouliermis et al. 2001; Table 6 of Braun et al. 1997).

Thus, this huge coeval population gave rise to the need for a large-scale trigger, like an infalling cloud or a large shock front created by the movement of the LMC through the galactic halo (de Boer et al. 1998; de Boer 1998), while models with a central trigger or a propagation could be ruled out. SSPSF is therefore only valid on small scales (up to  $\sim 300$  pc) as it is visible on the rim, while the creation mechanism of LMC 4 has its origins on larger ( $\sim 1$  kpc) scales.



**Fig. 7.** a)  $H\alpha$  image of supergiant shell LMC 4 [left panel] made from a scan of a photographic plate taken with the Curtis Schmidt Telescope at Cerro Tololo (Kennicutt & Hodge 1986). The locations of some stellar associations and the borders of the two datasets (J and C, respectively) are marked. b) Sketch of selected structures [right panel] near LMC 4 (adapted from Fig. 2 of Efremov & Elmegreen 1998).



**Fig. 8.** CMDs of LMC 4 with Geneva isochrones (Schaerer et al. 1993;  $Z = 0.008$ ) of logarithmic ages  $\log(t/[\text{yr}]) \in \{7.05, 7.5, 8.0\}$  and extinction correction of  $A_V = 0.31$  mag.

- a) CMD with 46 749 data points of the central data set (C, see Fig. 7a) of LMC 4 [left panel].  
b) CMD with 15 787 d. p. of the LMC 4 'J' dataset (Braun et al. 1997) without fields 11-16 [right panel].  
In panel a) the crosses near  $M_V \approx -6.5$  mag are six A supergiants also marked in Fig. 7b.

Nevertheless, after these results further models with central trigger had been proposed by Efremov & Elmegreen (1998), describing three stellar arcs as triggered by central clusters (as given by the bows and boxes in Fig. 7b). Additionally, Efremov & Fargion (2000) presented a scenario, by which cluster arcs (now even four in the LMC 4 region and vicinity) are each pressurized by the collimated and precessing beam of a  $\gamma$ -ray burst / soft gamma repeater (originating in NGC 1978).



To further constrain the triggering mechanism, we observed three central fields (C) of LMC 4 (see Fig. 7a and Braun et al. 2000) in *B* and *V*. The resulting colour-magnitude diagram (Fig. 8a) has the same morphology as the one of the 'J' dataset excluding the overlapping region (Fig. 8b). The two clusters (HS 343 and KMHK 1000), which may have triggered star formation after Efremov & Elmegreen, are much too old (0.1 Gyr and 0.3 Gyr, respectively) to have stimulated further star formation in the birth cloud of LH 77. The triggering of different arcs does neither fit to a homogeneous coeval population nor to the morphology of LMC 4 in H I and H $\alpha$ .

With the stringent results of the good-quality<sup>2</sup> photometry available, it seems to be inevitable that LMC 4 has been driven and ionized by the massive stars of the coeval population inside the SGS, with about 5000 stars already exploded in supernovae of type II. Thus, the gas had been driven out of the central region in a turbulent fashion, causing an outbreak at the rear side and a component approaching with 11 km/s (Domgörgen et al. 1995). The star burst 12 Myr ago has been most probably driven by the bow-shock, resulting in a compression zone. Its location is currently, due to the LMC rotation (see Fig. 3), at the south eastern edge and thus may have caused the CO complex south of 30 Doradus (see Mizuno et al. 2001).

The updated and enhanced content of the articles (Braun et al. 1997, 2000, 2001a,b), incl. first results on SGSs LMC 7 and LMC 1, can be found with full discussion in Braun (2001).

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<sup>2</sup>The comparison of the three photometries (J, C, and Dolphin & Hunter 1998 [AJ 116, 1275]) shows good agreement. All three datasets are available electronically, see CDS J/A+A/328/167, J/AJ/116/1275, and AIUB FTP account, linked from the WWW pages given above (Braun et al. 2000).